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(56) Documents cited by ISA
EP 0258793 A EP 0198649 A EP 0025632 A
DE 2344263 A DE 1186648 A DE 1112350 A
US 4713917 A

(58) Field of search by ISA
INT CL^5 E04B, F16F, F16L, G10K

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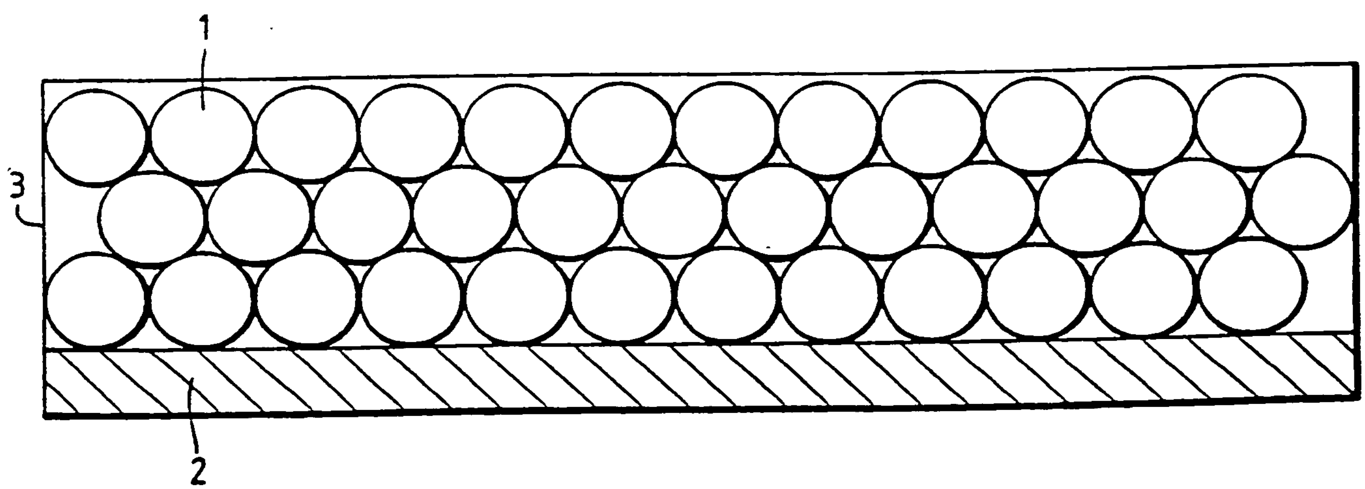
(54) Vibration damping materials

(57) For areas with restricted access such as box sections (3), pipes and wall sections, etc, vibration damping poses a problem as it may be difficult or impossible to apply conventional damping such as tiles and the use of lead shot or sand presents a weight problem. By using a vibration damping material consisting of a plurality of viscoelastic spheres (1) the ease of application is improved and effective damping achieved especially if a high density filler is included in the viscoelastic material. Application of viscoelastic spheres can be made to damp the vibration of any structure where the viscoelastic spheres can be suitably confined.



GB 2 241 300 A

PCT

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(81) Designated States: AT (European patent), AU, BE (European patent), CH (European patent), DE (European patent), FR (European patent), GB, GB (European patent), IT (European patent), LU (European patent), NL (European patent), SE (European patent), US.

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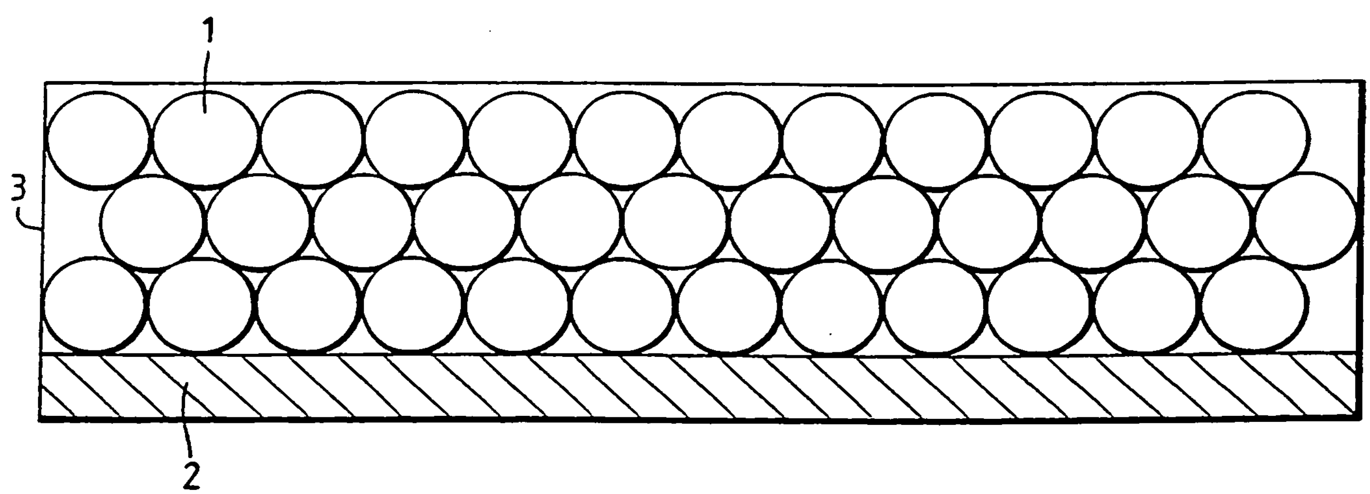
(54) Title: VIBRATION DAMPING MATERIALS



(57) Abstract

For areas with restricted access such as box sections (3), pipes and wall sections etc, vibration damping poses a problem as it may be difficult or impossible to apply conventional damping such as tiles and the use of lead shot or sand presents a weight problem. By using a vibration damping material consisting of a plurality of viscoelastic spheres (1) the ease of application is improved and effective damping achieved especially if a high density filler is included in the viscoelastic material. Application of viscoelastic spheres can be made to damp the vibration of any structure where the viscoelastic spheres can be suitably confined.

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VIBRATION DAMPING MATERIALS

The invention relates to materials for damping vibrations in structures, particularly but not exclusively hollow structures such as box sections, pipes, wall sections etc.

The damping of structural vibrations by means of applied tiles constructed either wholly or in part of viscoelastic polymers is well known. However, there are situations where these techniques are not practical, such as hollow cavity-like structures where it is physically impossible to gain access for tile application. In such situations it has been common practice to use granular fillings such as sand or lead shot to damp these structures. These treatments, however, are heavy and it is advantageous to use viscoelastic polymer materials as substantial savings in weight can be made.

The damping effect of viscoelastic layers is affected by motion of the layer in its "thicknesswise" direction. Damping can be improved by increasing the density of the layer or by increasing the layer thickness. Conventionally a viscoelastic layer is made in the form of a homogeneous layer which has a high loss factor in the frequency and temperature range of interest and may be cast in situ as a closed cell foam. Making the layer as a foam reduces the effective moduli of the layer and hence reduces the wave velocity. Thicknesswise resonances can then occur at low frequencies and it is also possible to make the layer thinner. A similar effect can be achieved by increasing the layer density by, for example, the addition of a high density filler.

These kind of viscoelastic treatments could be useful in damping cavities (eg box-section tubing) where the thickness of the layer will be controlled by the depth of the cavity. Any tuning of the damping performance has, therefore, to be done by variation of the wave velocity (c) which can be achieved by altering the volume fraction of air (ϕ). To tune for very low frequencies it becomes necessary to have a large air content but it can be shown that c will reach a limiting value where further increase in the air content is ineffective. Furthermore, increasing the air content reduces the layer density, to the detriment of good overall damping performance. It therefore becomes necessary to increase the layer density

by the addition of high density fillers. This does have the additional benefit of lowering c but the reinforcing effect of the filler on the polymer modulus tends to counteract this, and there is also a limit to the amount of filler that can be added.

The object of the invention is to provide a vibration damping material having a lower wave velocity than an air filled foam but which also maintains a density comparable to or greater than a solid viscoelastic polymer material.

The invention provides a vibration damping material comprising a plurality of viscoelastic spheres.

Spheres can be used to fill any size or shape of structure and can also be removed easily if required. There is no requirement for the mixing of materials as with foams and spheres of different materials can be used for different damping requirements. Preferably the diameter of each sphere is very much less than the wavelengths of the vibrations to be damped. For the damping of frequencies below 1kHz a maximum diameter of about 14mm is advantageous. Typically a useful range of sphere diameters is about 10mm to 15mm.

Advantageously the spheres used to damp a particular structure are all of a single size and polymer type. If the spheres are of a single size they can be close packed within the structure to give the maximum packing density. The small point areas of contact between individual spheres results in a layer of high compliance but the damping material retains a relatively high density determined by the packing density of the spheres (this is typically >0.6 x the density of the spheres' material).

Preferably the spheres are made of a viscoelastic polymer material. Any material that is in its viscoelastic state at the operational temperatures and frequency can be used, for example, epoxy resins or polyurethane. A typical example of the type of epoxy resin used is EP 25 which is available from Wessex Resins and Adhesives Ltd and which consists of EL 5 epoxy resin 100 gm, EL 1 epoxy modifier 100 gm and EHT 3 hardener 75 gm. If extra weight is acceptable, a high density filler is preferably included in

the material as this improves the overall damping factor, which is dependent on the mass ratio of the spheres to the structure. Alternatively the spheres may be a high density material, such as steel or glass, coated with a layer of viscoelastic material.

The invention will now be described, by way of example only, with reference to the accompanying drawings, of which:

Figure 1 illustrates the effect on the damping factor of the thickness of a viscoelastic layer;

Figure 2 illustrates the effect on damping of increasing the density of the viscoelastic layer;

Figure 3 illustrates the effect on damping of increasing the thickness of the viscoelastic layer;

Figure 4 illustrates the effect on wave velocity of increasing the air content of the viscoelastic layer;

Figure 5 shows an experimental arrangement of spheres packed on a steel beam;

Figure 6 illustrates the predicted and measured damping factors for the steel beam shown in Figure 5 packed with viscoelastic spheres to a depth of 30mm; and

Figure 7 illustrates the predicted and measured damping factors for the steel beam shown in Figure 5 packed with viscoelastic spheres to a depth of 80mm;

Figure 8 illustrates the frequency response of undamped 10 mm thick steel;

Figure 9 illustrates the frequency response of the same steel as in Figure 8 but damped with low density viscoelastic spheres;

Figure 10 illustrates the frequency response of the same steel as in Figures 8 and 9 but damped with high density polyurethane spheres;

Figure 11 illustrates the frquency against damping factor for various types of beam containing viscoelastic spheres of composition EP 25 as mentioned herein;

The damping factor for a thick homogeneous viscoelastic layer when applied to a plate can be given by:

$$\delta_1 = \frac{\dfrac{\delta_2}{(1-\delta_2^2)^{1/2}}\left[\dfrac{\sinh 2k''H}{2k''H} - \dfrac{\sin 2k'H}{2k'H}\right]}{\dfrac{\sinh 2k''H}{2k''H} + \dfrac{\sin 2k'H}{2k'H} + 2\mu\,[\cos^2 k'H + \sinh^2 k''H]} \qquad (1)$$

where: μ = $m/\rho_{eff}H$

m = mass of the plate

ρ_{eff} = effective density of the viscoelastic layer

H = thickness of the viscoelastic layer

k', k'' = real and imaginary parts of the compressional wave number where $k = 2\pi f/c$

f = frequency

c = compressional wave velocity

δ_2 = viscoelastic layer loss factor

Figure 1 illustrates a computation of this equation for a viscoelastic layer applied to a steel plate. It can be shown that the frequency (f_n) at which the first damping factor peak occurs is related to approximately a $\lambda/4$ resonance in the layer thickness and that subsequent peaks occur at every $(2n - 1)\lambda/4$ thus:

$$f_n = \frac{2n-1}{4H}\sqrt{\frac{P_{eff}}{\rho}} \qquad n = 1, 2, 3, 4 \ldots.. \qquad (2)$$

where P_{eff} = the effective plate modulus of the layer.

Furthermore, the damping can be improved by increasing the mass ratio u either as a result of increasing the density of the layer, as shown in Figure 2, or by increasing the layer thickness, as shown in Figure 3.

Increasing the air content of the layer reduces the effective modulus and hence reduces the wave velocity in the layer. Thicknesswise resonances can therefore occur at low frequencies and it is also possible to make the layer thinner. A similar effect can be achieved by increasing the layer density, for example by the addition of a high density filler. Thus:

$$c = \sqrt{\frac{P_{eff}}{\rho_{eff}}} \qquad (3)$$

where $P_{eff} = K_{eff} + \frac{4G_{eff}}{3}$

and

$$K_{eff} = K(1 - \phi)/(1 + (3K\phi)/(4G))$$

$$G_{eff} = G/[1 + 15\phi(1 - \sigma)/((1 - \sigma)(7 - 5\sigma))]$$

Where
K = polymer bulk modulus (complex)
G = polymer shear modulus (complex)
σ = Poisson's Ratio
ϕ = volume fraction of air in the foam

When viscoelastic treatments are used to damp cavities, the thickness of the layer is controlled by the depth of the cavity. Any tuning of the damping performance, therefore, has to be done by variation of the wave velocity (c), which can be achieved by altering the volume fraction of the air (ϕ). To tune for very low frequencies it would appear to be advantageous to have a large air content but it can be shown that c will reach a limiting value where further increase in the air content is ineffective. Typically, a wave velocity of 210 m/s for an effective density of 250kg/m^3 is the best achievable for an unfilled polymer in the middle of its transition region. Figure 4 illustrates the effect for an epoxy resin polymer (consisting of epoxy resin, epoxy modifier and hardener in the proportions by weight of 100:100:75) at 200Hz and 20°C where:

K	=	3 GPa
G at 200 Hz	=	16.2 MPa
δ	=	0.9
ϕ	=	0.8
σ	=	0.4996

Increasing the air content also reduces the layer density, reducing the mass ratio μ, to the detriment of good overall damping performance.

Figure 5 shows an experimental arrangement of a damping treatment according to the invention. A layer of viscoelastic spheres 1, of a single size and made of a viscoelastic polymer material, is close-packed on a steel beam 2 and held in place by a box 3. The small point areas of contact between individual spheres results in a layer of high compliance which, however, retains a relatively high density determined by the packing density of the

spheres. The effective density of the layer is typically greater than 0.6 x the density of the material of the spheres.

If the assumptions are made that:

a) the spheres are identical;

b) the viscoelastic material is homogeneous and isotropic;

c) the packing is statistically homogeneous and isotropic;

d) the viscoelastic material has an infinite coefficient of friction;

e) the diameter of the spheres is very much less than the wavelength; and

f) there is a confining pressure to the packing that ensures good contact between individual spheres;

then it can be shown that packed spheres can be treated as a homogeneous medium with equivalent physical properties where the equivalent bulk modulus K* can be expressed as:

$$K^* = \frac{1}{6}\left[\frac{3E'^2\phi^2 n^2 p}{\pi^2(1-\sigma^2_{eff})^2}\right]^{1/3} \tag{4}$$

where
E' = the dynamic Young's Modulus of the polymer
n = the number of contact points
p = the hydrostatic confining pressure
σ_{eff} = $\sigma/2(5-3\sigma) = 0.07$ (assuming rough spheres ie coefficient of friction = 1)
ϕ = packing fraction of spheres

Hence:

$$c = \sqrt{E_{eff}/\rho_{eff}} \tag{5}$$

where
$E_{eff} = 3(1-2\sigma_{eff})K^*$
$\rho_{eff} = \rho\phi$

From observation, n is seen to be around 12 which implies that the packing is face centred cubic with a volume fraction of 0.74. From these formulae and using the same polymer as for the foam referred to with respect to Figures 1 to 4, a wave velocity of about 40m/s is obtained for an effective density of 925kg/m^3 at 200Hz. Applying this to the thickness effect damping

equation(1), predicted damping curves can be derived. Figures 6 and 7 show predicted and measured damping curves for 14mm diameter spheres of the polymer, on 10mm thick steel plate at 20°C, for a packing depth of the spheres of 30mm and 80mm respectively. In each case the $\lambda/4$ resonance is clearly illustrated at approximately 160Hz for the 80mm layer and 380Hz for the 30mm layer.

Figure 8 demonstrates the typical response of undamped 10 mm thick steel up to 1.6 KHz and Figure 9 shows the clear improvement in damping to be achieved by damping with low density viscoelastic spheres. However Figure 10 demonstrates particularly good levels of damping which can be achieved under the right conditions over a wide frequency range at least up to 1.6 KHz by utilising high density viscoelastic spheres.

From Figure 11 it can be seen that damping factor changes with frequency and the dimensions of the object being damped.

It can be seen from the Figures that a packing of viscoelastic spheres can result in significant damping factors. The peak in the damping factors is related to a $\lambda/4$ thicknesswise resonance across the depth of the spheres though variation of the depth of the spheres is, in practice, restricted by the size of the cavity to be filled. However, the level of the overall damping factor is dependent on the mass ratio of the spheres to the structure and this may be improved by raising the density of the sphere's material, either by the addition of a high density filler, for example a dispersion of particulate iron oxide throughout the viscoelastic material, or by applying a coating of a viscoelastic polymer to a high density sphere of, for example, steel or glass. This arrangement will have advantages where the loss of the weight saving advantages of the use of a polymer is acceptable. Further improvements may be achieved by variation of the polymer modulus characteristics.

The damping material of the invention can be used in any hollow structure where damping is required, such as pipe structures, wall sections, box section beams etc. It can provide significant improvements in damping without causing significant increased weight problems.

CLAIMS

1. A vibration damping material characterised in that it comprises a plurality of viscoelastic spheres.

2. A vibration damping material according to claim 1 characterised in that the diameter of each sphere is very much less than the wavelengths of the vibrations to be damped.

3. A vibration damping material according to claim 1 characterised in that the spheres are all of a single size and polymer type.

4. A vibration damping material according to any one preceding claim characterised in that the spheres are made of a viscoelastic polymer material.

5. A vibration damping material according to claim 4 characterised in that the viscoelastic polymer material is an epoxy resin.

6. A vibration damping material according to claim 4 characterised in that the viscoelastic polymer material is polyurethane.

7. A vibration damping material according to claim 1 characterised in that a high density filler is included in the material.

8. A vibration damping material according to claim 7 characterised in that the high density filler is particulate iron oxide.

9. A vibration damping material according to claim 1 characterised in that the spheres are made of a high density material, such as steel or glass, coated with a layer of viscoelastic material.

Fig. 1.

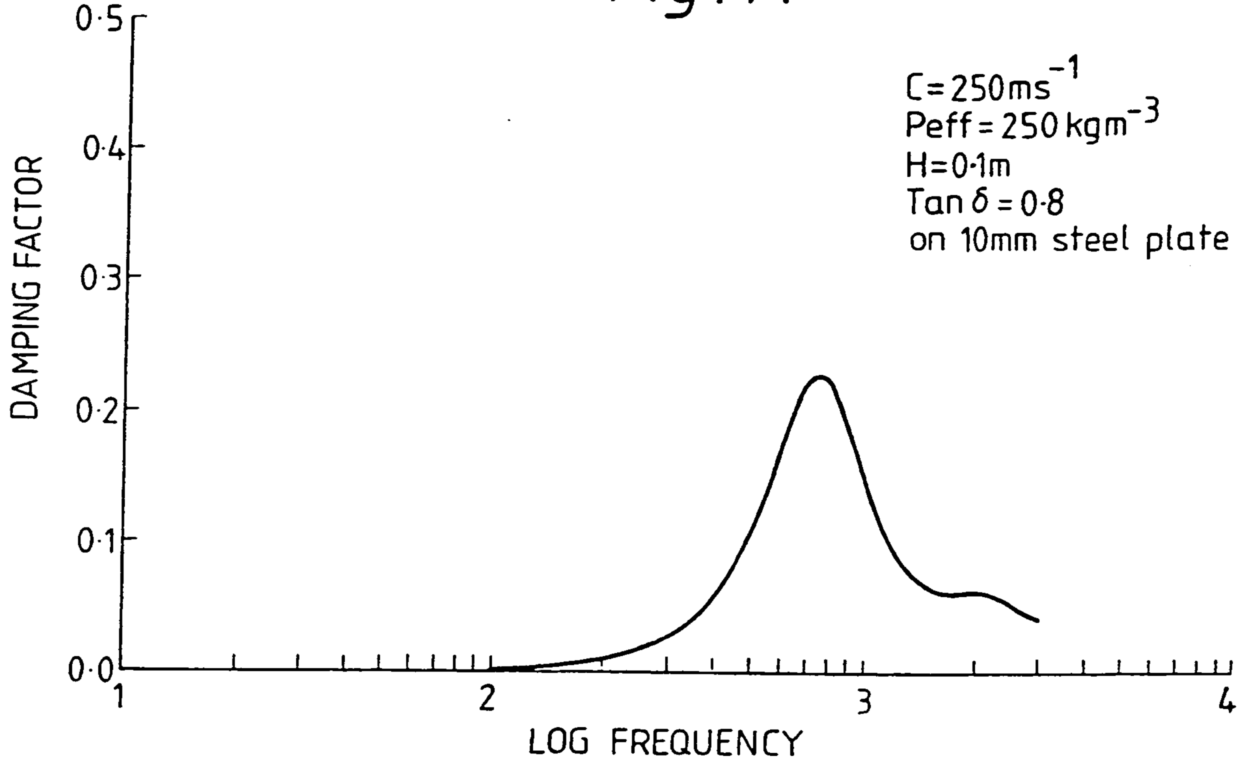

C=250ms⁻¹
Peff = 250 kgm⁻³
H=0·1m
Tan δ = 0·8
on 10mm steel plate
DAMPING FACTOR
0·0
0·1
0·2
0·3
0·4
0·5
1
2
3
4
LOG FREQUENCY

Fig. 2.

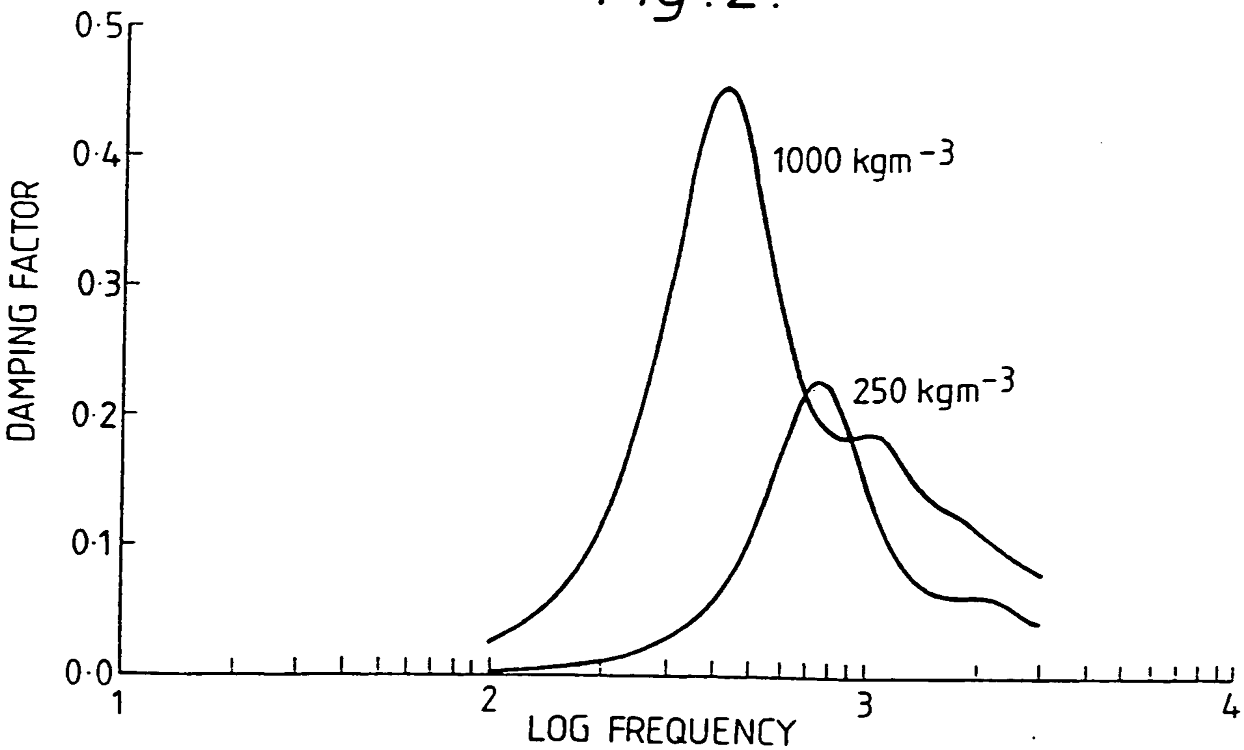

1000 kgm⁻³
250 kgm⁻³
DAMPING FACTOR
0·0
0·1
0·2
0·3
0·4
0·5
1
2
3
4
LOG FREQUENCY

Fig. 3.

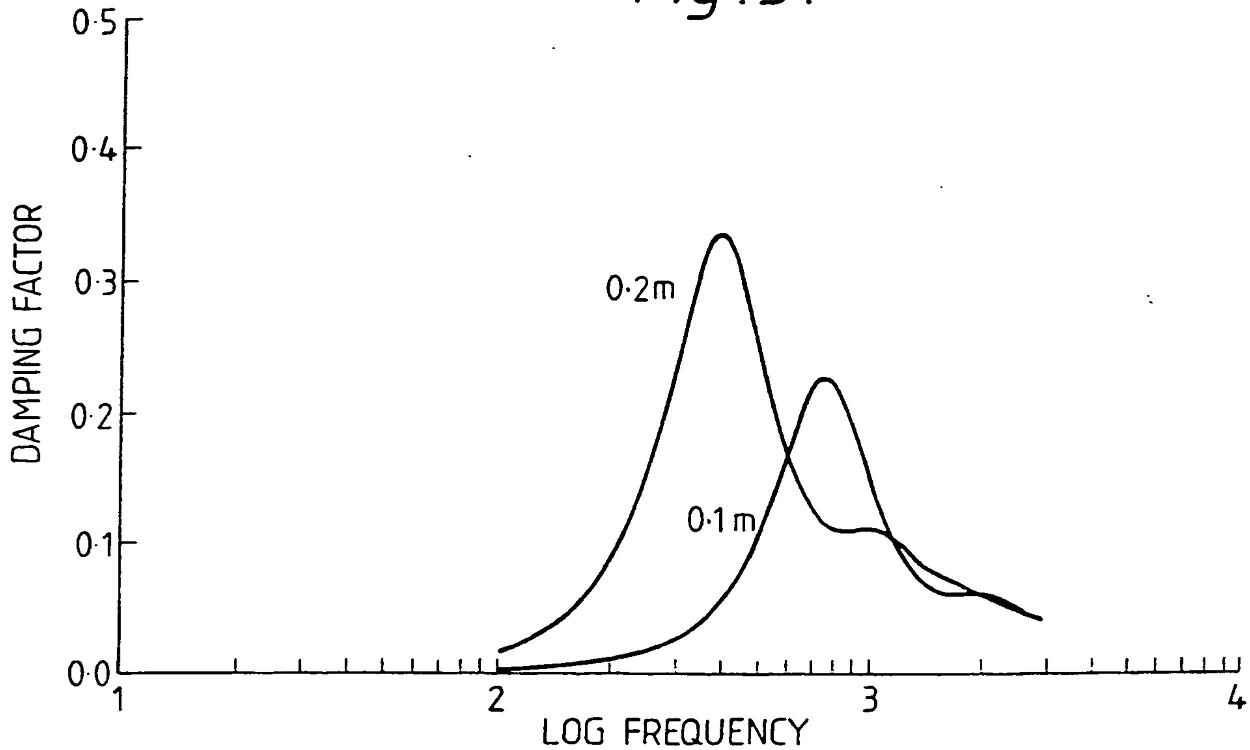

0·5
0·4
0·3
0·2
0·1
0·0
DAMPING FACTOR
0·2m
0·1m
1
2
3
4
LOG FREQUENCY

Fig. 4.

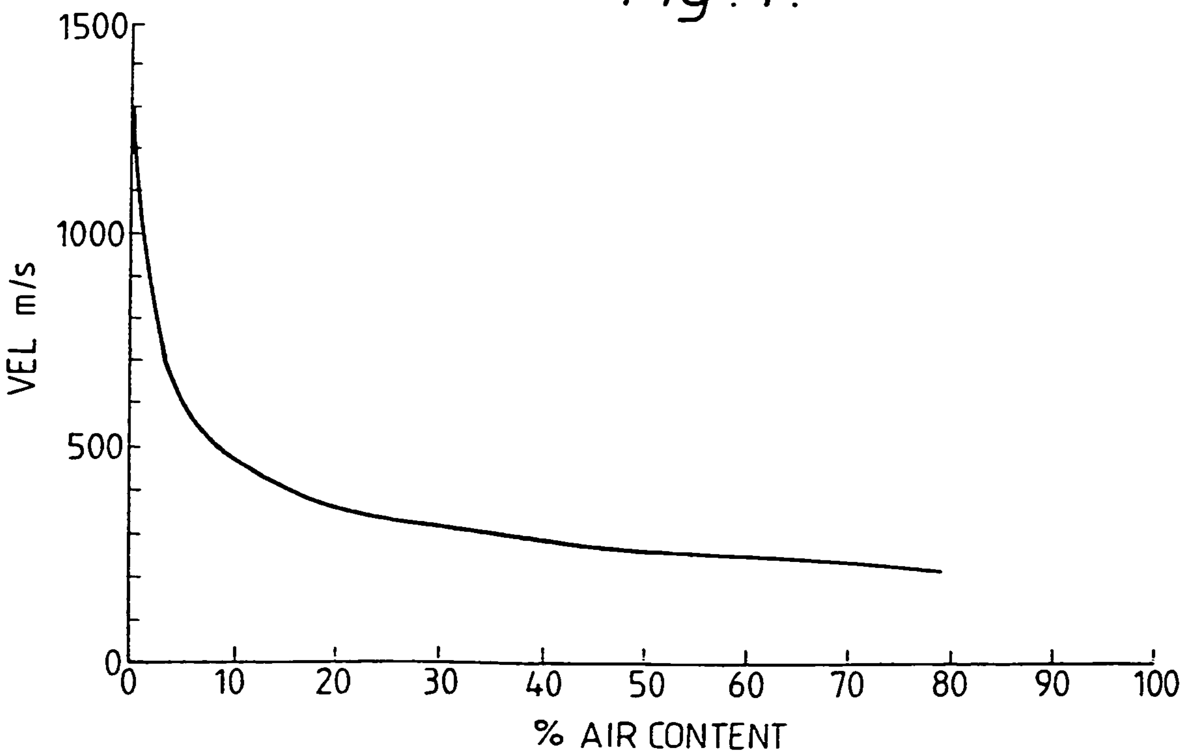

1500
1000
500
0
VEL m/s
0
10
20
30
40
50
60
70
80
90
100
% AIR CONTENT

Fig. 5.

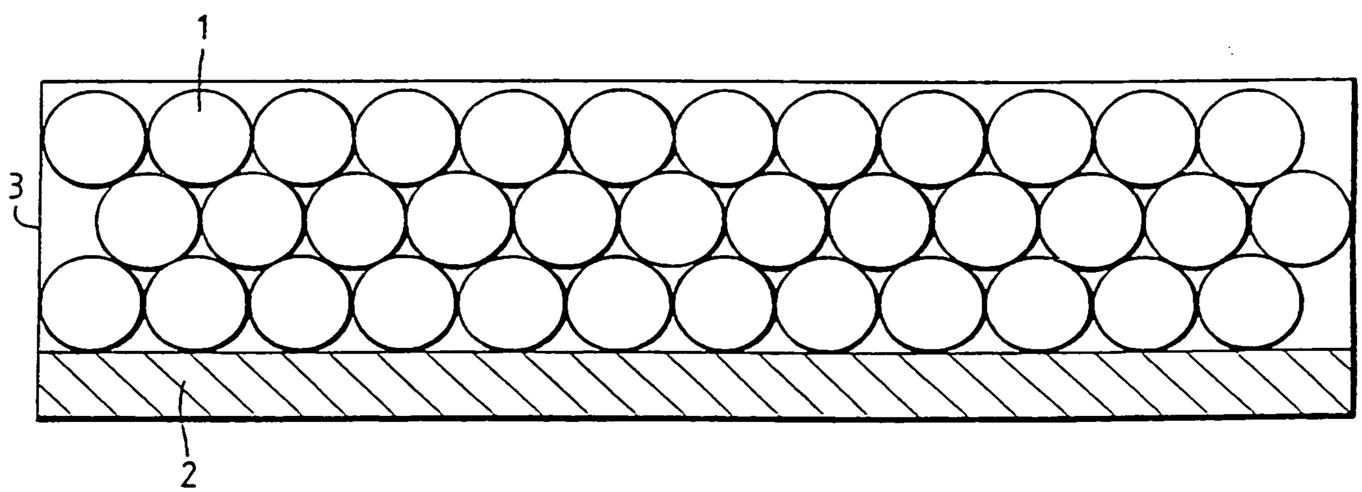

1
3
2

Fig. 6.

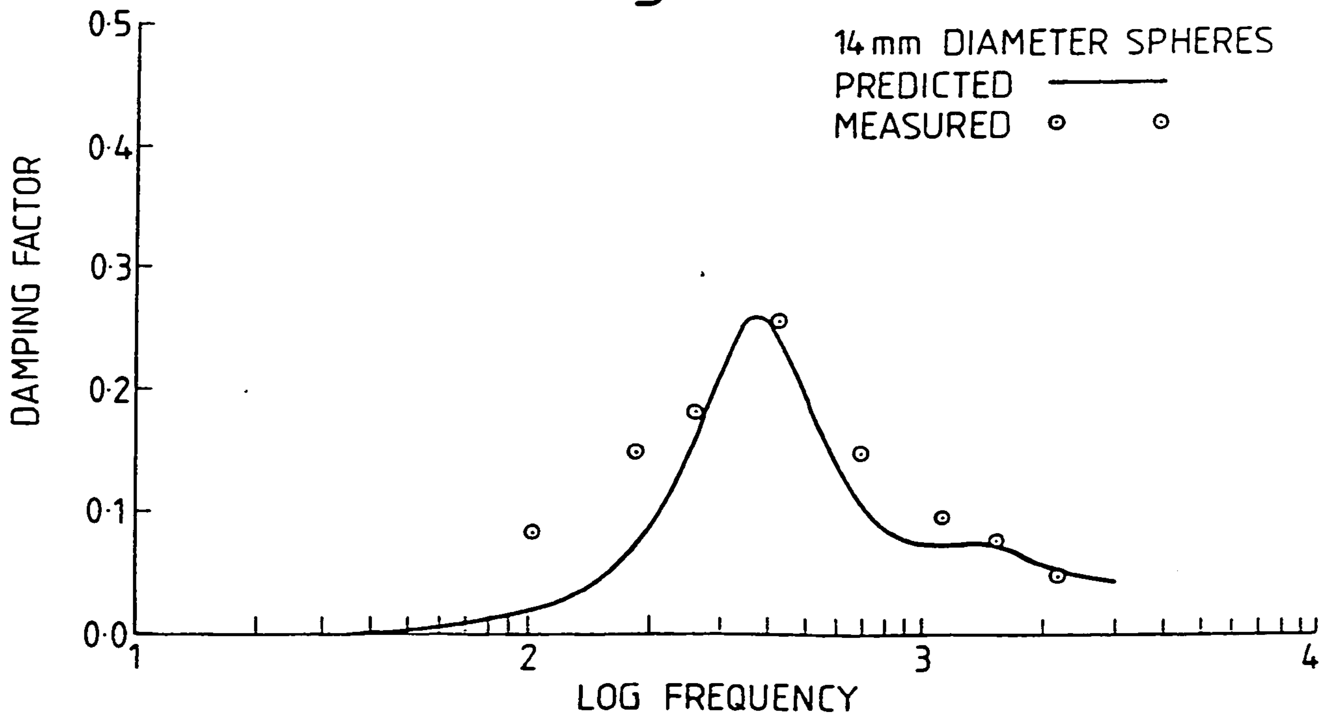

14 mm DIAMETER SPHERES
PREDICTED
MEASURED
DAMPING FACTOR
0·5
0·4
0·3
0·2
0·1
0·0
1
2
3
4
LOG FREQUENCY

Fig. 7.

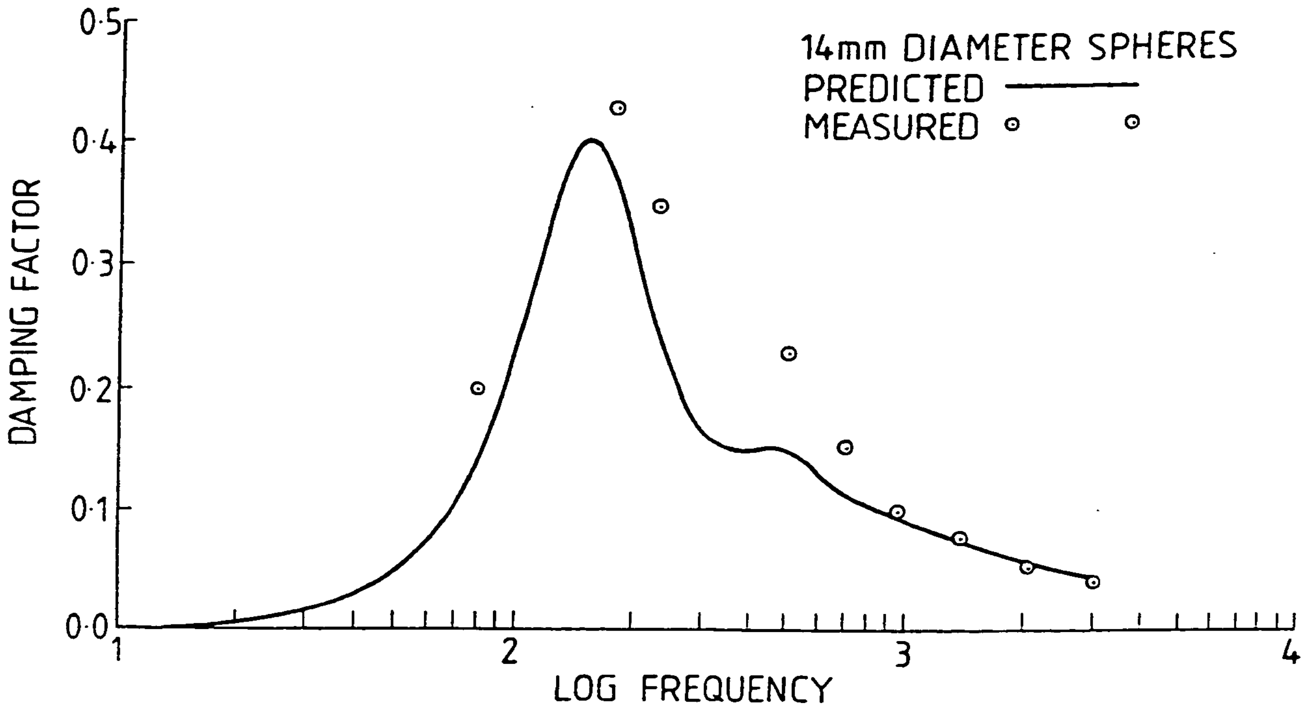
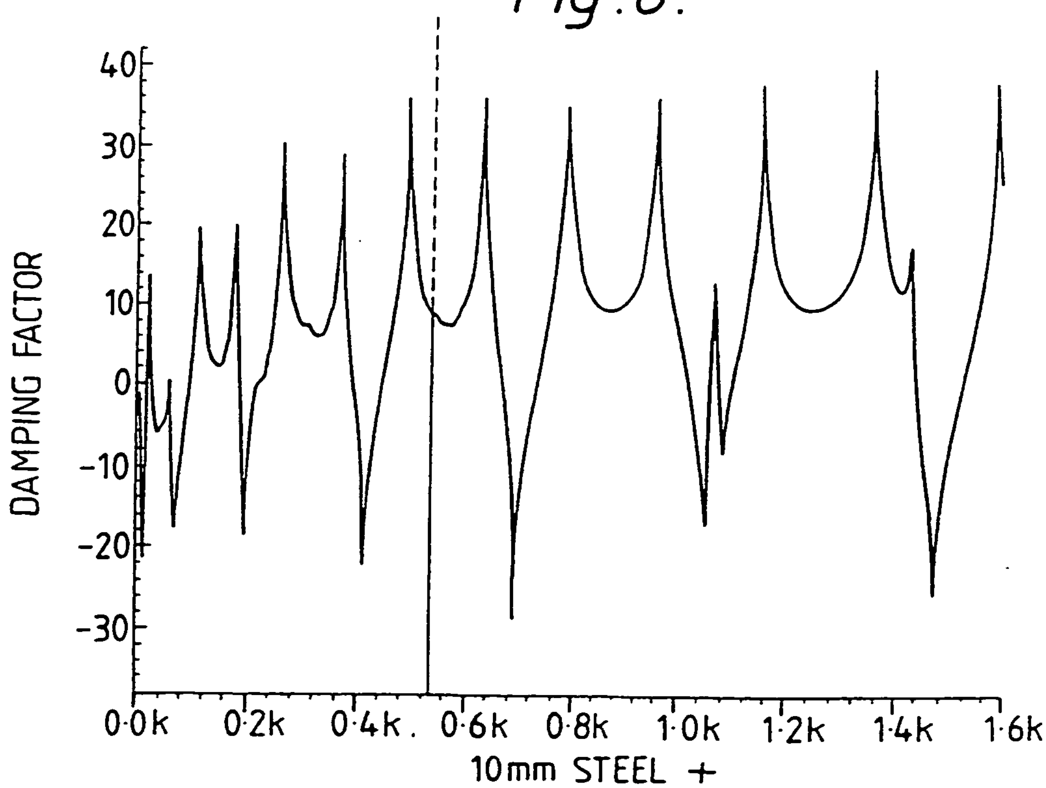


Fig. 8.



SUBSTITUTE SHEET

Fig. 9.

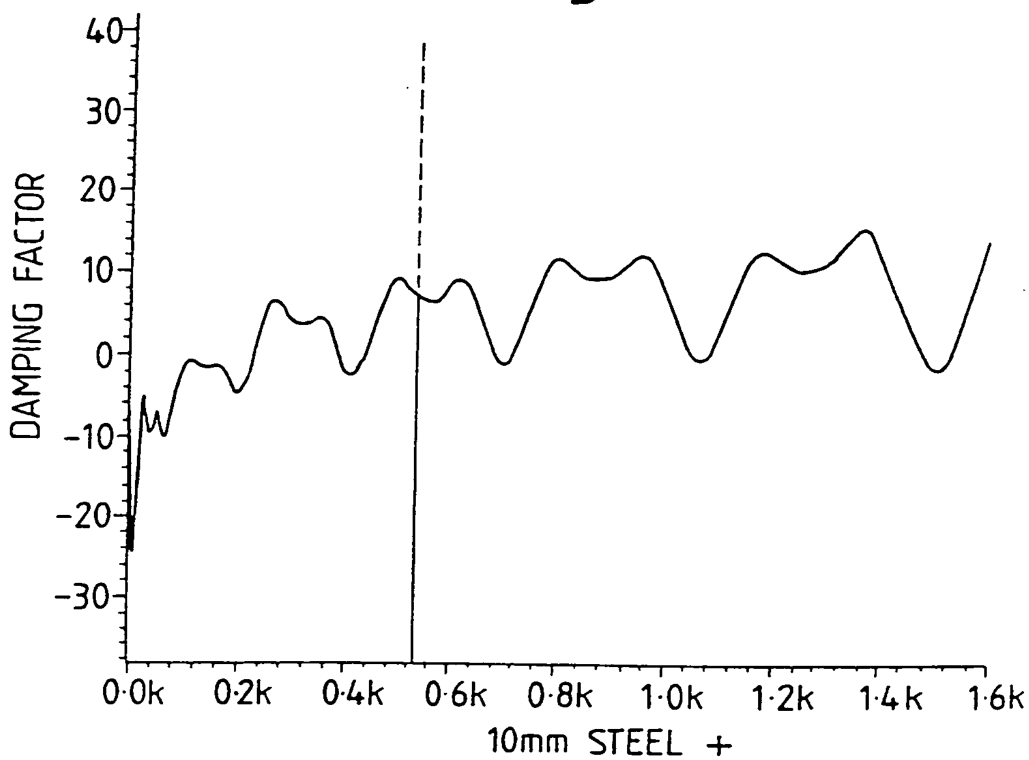

40
30
20
10
0
-10
-20
-30
DAMPING FACTOR
0·0k 0·2k 0·4k 0·6k 0·8k 1·0k 1·2k 1·4k 1·6k
10mm STEEL +

Fig. 10.

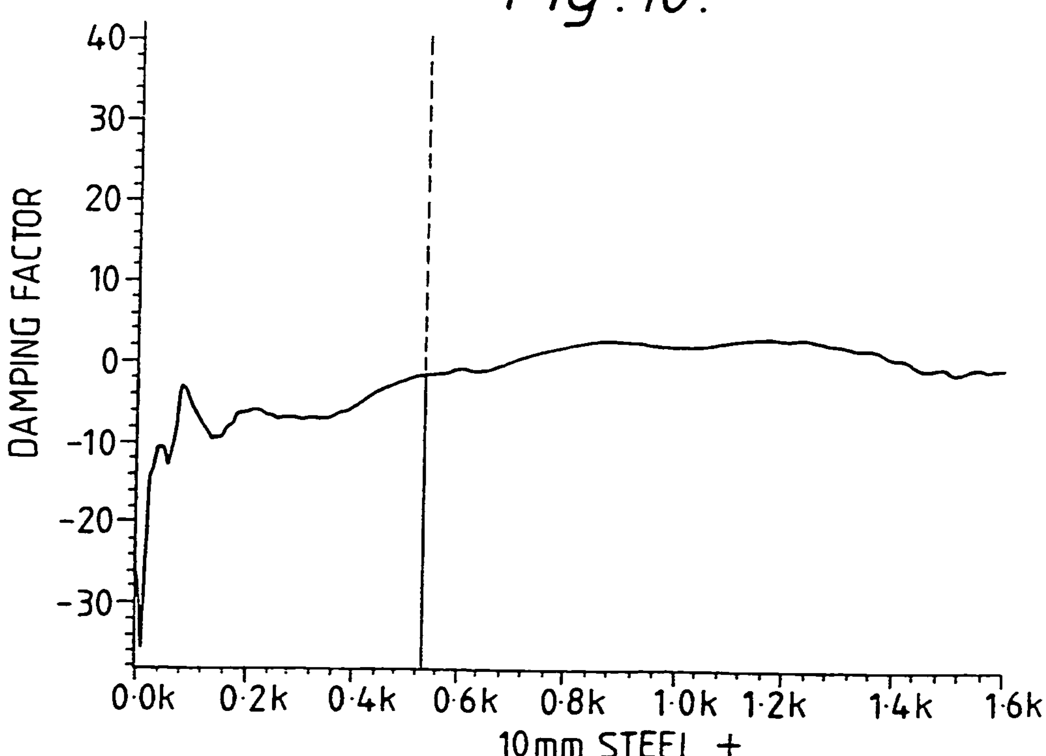
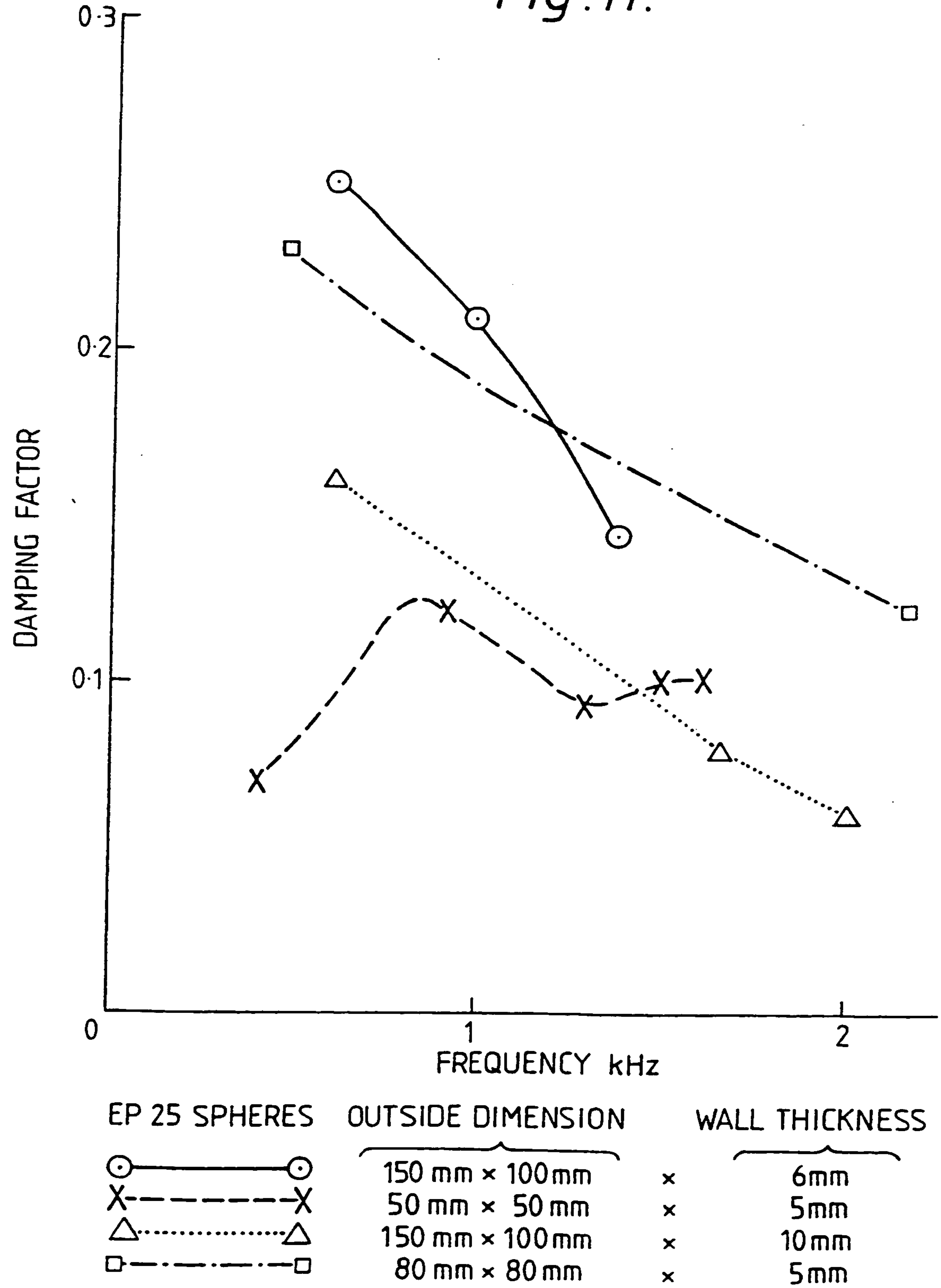

40
30
20
10
0
-10
-20
-30
DAMPING FACTOR
0·0k 0·2k 0·4k 0·6k 0·8k 1·0k 1·2k 1·4k 1·6k
10mm STEEL +

Fig. 11.


0·3
0·2
0·1
0
DAMPING FACTOR
1
2
FREQUENCY kHz
EP 25 SPHERES
OUTSIDE DIMENSION
WALL THICKNESS
150 mm × 100 mm × 6 mm
50 mm × 50 mm × 5 mm
150 mm × 100 mm × 10 mm
80 mm × 80 mm × 5 mm

INTERNATIONAL SEARCH REPORT

International Application No PCT/GB 89/00869

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all)[6]

According to International Patent Classification (IPC) or to both National Classification and IPC

Int.Cl. 5 F16F7/00 ; G10K11/16

II. FIELDS SEARCHED

Minimum Documentation Searched[7]

Classification System	Classification Symbols
Int.Cl. 5	F16F ; G10K ; E04B ; F16L

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched[8]

III. DOCUMENTS CONSIDERED TO BE RELEVANT[9]

Category °	Citation of Document, [11] with indication, where appropriate, of the relevant passages [12]	Relevant to Claim No.[13]
X	EP,A,0025632 (PH. DELHEZ) 25 March 1981 see page 4, line 33 - page 5, line 11 see page 7, line 25 - page 9, line 5; figure 2	1, 3, 4
A		2, 5, 6
X	DE,A,2344263 (FRIED. KRUPP GMBH) 13 March 1975 see figures 2, 3 and claims 1, 2	1, 3, 4
A	DE,A,1186648 (REVERTEX LTD) 04 February 1965 see the whole document	3-8
A	EP,A,0258793 (TATSUTA ELECTRIC WIRE & CABLE) 09 March 1988 see claims 1-5	5-8
A	US,A,4713917 (I.G. BUCKLE) 22 December 1987 see claims 1, 5, 6; figure 10	1, 9

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° Special categories of cited documents : [10]

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"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
30 OCTOBER 1989	22. 11. 89
International Searching Authority	**Signature of Authorized Officer**
EUROPEAN PATENT OFFICE	T.K. WILLIS

1

III. DOCUMENTS CONSIDERED TO BE RELEVANT (CONTINUED FROM THE SECOND SHEET)

Category °	Citation of Document, with indication, where appropriate, of the relevant passages	Relevant to Claim No.
A	DE,A,1112350 (UNITED AIRCRAFT CORP.) 03 August 1961 see claims 1, 2; figures 4, 5 ---	1, 9
A	EP,A,0198649 (MELLES GRIOT, IRVINE CO.) 22 October 1986 see page 9, line 6 - page 10, line 9; figures 2, 3, 6 ---	1, 3, 9

ANNEX TO THE INTERNATIONAL SEARCH REPORT ON INTERNATIONAL PATENT APPLICATION NO. PCT/GB 89/00869

SA 30376

This annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report.
The members are as contained in the European Patent Office EDP file on 14/11/89
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Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP-A-0025632	25-03-81	BE-A- 878854	16-01-80
DE-A-2344263	13-03-75	None	
DE-A-1186648		GB-A- 1016432	
EP-A-0258793	09-03-88	JP-A- 63060144	16-03-88
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		CA-A- 1250865	07-03-89
		JP-A- 61036466	21-02-86
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For more details about this annex : see Official Journal of the European Patent Office, No. 12/82